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# THE COMPOSITION OF SOME ALBERTA IRRIGATION WATERS AND THEIR EFFECTS ON THE SOIL

Frank R. Low

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April, 1942.

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# THE COMPOSITION OF SOME ALBERTA IRRIGATION WATERS AND THEIR EFFECTS ON THE SOIL

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Department of Soils

A THESIS

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# THE COMPOSITION OF SOME ALBERTA IRRIGATION WATERS AND THEIR EFFECTS ON THE SOIL

FRANK R. LOW

## INTRODUCTION

The purpose of this investigation was to determine the composition of Alberta irrigation waters, and to determine if possible the effects that these waters would have on the soils to which they are applied.

The commencement of a systematic and extensive system of irrigation in Alberta dates back to 1900, when on September fourth of that year, the main canal of the Alberta Railway and Irrigation Company (now known as the C. P. R. Lethbridge Block) was formally opened. Since that time, particularly in the period from 1910 to 1923, other large projects were developed so that at present there are about a million acres "under the ditch" and about half a million are actually being irrigated. There are indications that irrigation will be increased. Keeping this in mind, one can readily realize the need for an investigation into the composition and concentration of Alberta irrigation waters and their effects on the soil. According to Kelley (15)

the expression "composition and concentration" is preferable to the word quality.

Widtsoe (34) in emphasizing the need for water surveys, makes the following statement. "Systematic chemical surveys of irrigation waters should be made in connection with the study of the soils to which the waters are to be applied. Only when such data are abundantly at hand will it be possible to formulate for each section irrigation practices that will be permanently satisfactory. In the present stage of irrigation progress, it has become very important to know the composition of irrigation waters. As irrigation becomes older more problems will arise, many of which can be solved only by a more thorough knowledge of the waters used on irrigated soils. Water surveys are as legitimate in irrigated districts as are soil surveys."

Irrigation is used as an aid to crop production. Incidentally its use is likely to materially modify the chemical, physical and biological properties of the soil. There are five ways in which these changes may occur. These are as follows: (1) Water may increase or decrease the availability of plant-food without changing the total quantity. (2) Water may carry from a soil plant-food, thus leaving it intrinsically less productive. (3) Water may carry to a soil phosphorus, potassium, nitrogen, etc., therefore increasing its total plant food. (4) Water may carry to and deposit on a soil considerable quantities of silt, which will affect the physical properties of the soil. (5) Water may carry to and

deposit in a soil, alkali salts which in time will render it barren. The concentration of alkali salts sometimes becomes too great for plant growth, or produces an undesirable physical condition of the soil making it extremely difficult to work, and unfavorable for plant growth. These two kinds of effects may occur separately or together.

## REVIEW OF LITERATURE

Scientific workers and irrigation farmers have long been aware of physical changes brought about in the soil by the use of irrigation water. It was observed at the Dominion Experimental Station at Lethbridge, Alberta, that irrigation practiced over a number of years affected the tilth of the soil, rendering it more difficult to obtain a friable, mellow seed bed. Dr. Fairfield, Superintendent of the experimental farm, in bringing this matter to the attention of the Division of Chemistry at Ottawa (31) states that after a few years of irrigation the soil runs together, acting when plowed in the spring more or less as a refractory clay loam, i.e. it does not readily break down into a desirable looseness of texture and does not crumble into a good mulch. Similar soil on a dry land area that has never been irrigated can be ploughed in the spring and worked down into a very desirable seed bed. Dr. Fairfield emphasizes the importance of good tilth to the sugar beet grower. The poor physical condition of the soil in the spring of the year makes it difficult for the beet seedling to get a good start and in the fall of the year it makes the digging of root crops more difficult. W.D.Porter (26) in a radio address points out that sugar beets and other specialized crops are the most profitable for the irrigation farmer. There is every indication that sugar beet production along with other specialized crops will be increased on the

irrigated lands of Alberta. Thus the need for maintaining good tilth under irrigation becomes quite evident.

As a first step towards solving this problem, soil samples were taken from two adjoining areas. One had been heavily irrigated and the other had received very little irrigation water. These samples were analyzed by the Division of Chemistry at Ottawa. The chief point of difference between the two areas was in the calcium content of the soil. The results show that there has been a steady removal of calcium carbonate under heavy irrigation to a depth of over two feet. At a depth of two and one-half to three feet there is a greater calcium carbonate content in the irrigated than in the unirrigated profile. This would indicate that there has probably been some calcium carbonate removed from the surface layers. Dr. Shutt observes that the poor tilth occurring in the surface soil of the heavily irrigated land is probably due, at least partially, to this removal of calcium carbonate. This would be particularly true if there was an increase in sodium and potassium, accompanying leaching of calcium carbonate. The results also show leaching of other elements.

It has long been known that certain salts, particularly those of sodium and potassium, tend to deflocculate the soil and produce an undesirable physical condition. Calcium is generally considered to have a desirable physical effect on the soil in promoting granulation and making the soil more permeable to water. However, calcium salts may have just the opposite

effect under certain conditions. Harris (12) states that the cementing material in hardpan formation is often calcium carbonate but may be other materials such as hydrates of iron, alumina and silica.

Peele (24 & 25) added varying amounts of calcium to three clay loam soils. He found that there was a decrease in permeability in each case as measured by the percolation rate in artificially packed tubes. He attributes the depressing effect of calcium carbonate on the percolation rates to a dispersing effect of lime on the water stable granules. He also describes an experiment in which he shows that the addition of calcium carbonate caused the soil to bake into hard masses. One inch cubes of soil containing calcium carbonate additions at the rate of, from four to sixteen tons per acre were molded at the sticky point. They were then air dried for six weeks before crushing. The addition of four tons per acre of calcium carbonate increased the average weight per square inch required to crush the cubes by 85 pounds. Further additions of calcium carbonate increased the "crushing weight" by only a few pounds.

Peele (25) found that adding organic matter to the soil increased the permeability, probably because less compaction in the soil is obtained when large amounts of organic matter are present. A number of other workers (5) report beneficial effects from the addition of organic matter.

Botkin and Shires (2) found that the principal change from forty years of irrigation agriculture on desert soils, was a leaching of calcium carbonate to lower horizons. Changes in

other constituents including potash, phosphorus, nitrogen and organic matter, were small and not very significant. The composition of the soluble matter of the irrigation water had not materially changed during forty years.

Widtsoe (34) states that the force with which soil particles are held together depends primarily upon three factors (1) the physical constitution of the soil; (2) the water content; (3) the presence of various salts. More recent texts (1,13,14,20) emphasize the importance of the colloidal content of the soil in determining its physical properties. When a soil in a plastic condition has been worked until its pore space is much reduced, it becomes practically impervious to air and water, and is said to be puddled. The presence of gelatinous and viscous colloidal materials seems to be the controlling factor in such a condition, the pore space of a puddled soil being filled with such material. When a soil in this condition dries it is hard and dense.

According to Widtsoe (34) when irrigation water is applied to certain soils, the soil mass expands, only to contract gradually as water is lost by evaporation and transpiration. At the first irrigation the soil expands, and then contracts to a certain definite degree; at the second irrigation the soil does not expand quite so much, but contracts a little more than at the first irrigation; at the third irrigation the expansion is yet smaller and the contraction proportionally larger. At each successive irrigation the soil becomes more and more compact, until a condition of natural

packing is reached at which the expansion and contraction after each irrigation are so nearly the same as to result in no practical volume change.

In referring to the effects of suspended material on the physical properties of the soil, Widtsoe makes the following statement. "On a sandy soil the river silts usually bind the soil together and makes it more firm, of better water holding power, and of easier cultivation. On heavy clay, if the river sediment is of a loamy character, the clay is mellowed and lightened and therefore improved. However, if the silt is very fine or of a clayey nature, its application to a clay soil or even to a loam soil might be a disadvantage because of the finer texture that it would produce. Herein lies the danger of using irrigation water that carries considerable quantities of suspended matter. River mud is usually of a very fine texture. When dry it crusts and forms a hard covering which does not readily admit water or air into the soil. This necessarily interferes seriously with plant growth. One season's irrigation is not greatly injurious, but repeated year after year, unless proper cultural treatments are employed, it may result disastrously." Widtsoe recommends that the silt deposit be thoroughly plowed into the soil each fall or spring.

Greaves (7) points out that the Valley of the Nile has become famous in irrigation history not entirely because it is among the first known irrigated districts of the world, but also because of its extremely fertile fields, the fertility of which has been maintained throughout the ages. The valley owes its fertility to the flood waters which carry to it rich deposits of silt each year.

The soluble material in irrigation waters plays an important role in maintaining the fertility of the soil. Greaves (7) estimates that the rivers of North America carry to the ocean each year 474,000,000 tons of soluble constituents, a quantity sufficient to cover a hundred acres to a depth of nearly three thousand feet. He found 16.7 pounds of potassium, 11.4 pounds of nitrogen and 1.8 pounds of phosphorus to be the average quantities of these three important plant foods contained in one acre foot of water from the streams of the intermountain region.

Hundreds of samples of water representing fifty-eight streams, the majority of which are extensively used for irrigation purpose, were analyzed at the Utah Experimental station (8 & 9). Greaves (7 & 10) states that the potassium content of these waters varies from 59 parts per million to only 0.79 parts per million. The average potassium content of an acre foot of water would be sufficient to produce 15 bushels of wheat or 2 tons of sugar beets. He reports the total phosphorus content of the waters analyzed as varying from traces to 5.47 parts per million. The great majority of streams contained less than one part per million. The amount of phosphorus in an acre foot from the richest stream is sufficient to produce 60 bushels of wheat or 16 tons of sugar beets. He found the average nitrogen content in an acre foot of irrigation waters to be 11 pounds, while that in the highest was 66 pounds. This latter amount would be sufficient to produce 57 bushels of wheat or 8 tons of sugar beets. An examination of the results as given by Clarke (3) tends to bear out these statements.

Alkali salts play an important part in the physical and chemical changes produced in the soil by the use of irrigation water. Kelly, Brown and Liebig, Jr. (16) report that saline irrigation waters react with soils by base exchange with resulting absorption of sodium by the soil. This effect increased with increasing concentrations of solution and also as the ratio of Na: Ca. increased. The presence of absorbed sodium in the soils affected their physical properties adversely. They found that the ratio of Na: Ca had considerable influence on the absorption of sodium. When the ratio was not greater than 2 to 1 very little sodium was absorbed, but as the ratio exceeded 2 to 1 the absorption of sodium tended to increase proportionately. They, however, conclude that the ratio should not be greater than 1 to 1 when considering the soil solution, salts already present in the soil, evaporation, etc., except in the case of very dilute irrigation waters. Their results show that the kind of base present in the soil, influences the absorption of sodium. Less sodium was absorbed from a given solution when the soil was calcium saturated than when it was magnesium saturated.

Puffels (27) reports that large quantities of lime tend to preserve the stability of the soil and to decrease the rate of deterioration. His results show that when very saline water is used for irrigation under favorable climatic and drainage conditions such as are present in Beersheba basin (Southern Palestine), the salts do not accumulate but instead an alkaline soil will in time be formed by base exchange.

Kelley, Brown and Liebig, Jr. (16) and Kelley and Cummins (17 & 18) report harmful effects on the physical and chemical properties of soils leached with saline solutions. They attribute the changes to substitution of bases. A number of other workers report similar results (6, 7, 29). The voluminous literature on base exchange is too extensive to be reviewed here. MacGregor (20) gives an extensive review of the literature on base exchange.

Much of the alkali troubles arising out of irrigation lies not with the water but in the land itself. One of the most common and practical ways of improving an alkali soil is by leaching with excessive amounts of irrigation water. The extensive work of Scofield and Headley (30) and Kelley and Thomas (19) shows the need of water of low concentration along with suitable salts such as calcium sulphate or aluminum sulphate for reclaiming alkali soils.

Marshall and Palmer (22) found that the removal of salts from a solonetz type of soils at Tilley, Alberta, has been slow during the past twenty years. There is still a favorable condition with regard to the type of salt present in the soil complex as calcium remains the predominant cation.

Green and Peto (11) carried out an elaborate investigation to ascertain whether subsoil salts moved upwards under the influence of irrigation. They found that the small apparent changes which occur under normal irrigation and cultivation are largely due to swelling and shrinking of the surface soil, occasioned by changes in moisture content, and

to mechanical disturbances and settling which depend on cultivation. Apart from these apparent changes there may be a small downward movement of salt through the soil material. They found no upward movement. They also found that when the salt content of the surface soil is increased by application of fertilizers or other means, rain and weathering rapidly wash down the salt and in the course of time the soil column returns to its normal profile. An inverted profile of six feet in depth returned to a salt distribution resembling that of normal soil, after three years time following 36 waterings and 4 rains.

Salts introduced by the irrigation water are also washed down from the surface layers. The observations they (11) record show an increase in the average salt content of a six foot column of soil which is roughly equivalent to the amount of salt introduced by the irrigation water (about 1 ton per acre per 3 years).

Harris (12) has shown that alkali, principally sodium chloride, is very readily transported from one portion of the soil to another, either upward or horizontally. Salts become very concentrated in the upper inch or two of the soil where the water was allowed to evaporate. In his book on 'Soil Alkali', Harris says: "The extent to which salts move with water passing through a soil has been studied by a number of investigators..... Tulaykov found salts moved gradually and more or less completely to the surface of a column of soil 150 cm. in height supplied with water at the bottom. Hilgard

as well as Puchner and others have noted a migration of salts upward and downward as the moisture changed places." Puchner found the movement to depend somewhat on the chemical and physical properties of the soil. "Kossovich reports a greater movement on a loess clayey soil than on a sandy soil and sodium chloride hastened the rise of water while sodium carbonate impeded it." The literature on the movement of salts in the soil is quite extensive and cannot be reviewed here.

Scofield's (27) work on salt balance in irrigated areas shows the need for maintaining a favorable relation between the quantity of dissolved salts delivered to an area by the irrigation water, and the quantity removed from the area by the drainage water. A favorable salt balance exists when the total output of salts equals or exceeds the total input. The salt balance is unfavorable when the total input exceeds the output.

## The Source of Dissolved Materials in Irrigation Water

The composition of river waters varies from time to time and from place to place. The water varies in concentration between times of flood and times of drought and its composition is changed by incoming tributaries. It is also modified by seepage from the river banks, and the additions to the salinity of a river from this source may be of considerable magnitude. In arid regions occasional heavy showers may dissolve large quantities of salts from the soil and wash them into the rivers.

Although the minerals that form the rocky crust of the earth are relatively insoluble in water, they are not absolutely so. The feldspars are especially susceptible to change through aqueous agencies, yielding up their lime and alkalies to percolating water and forming a residue of clay. The average composition of the river and lake waters of North America (excluding the great basin) and of the rivers of the world as given by Clarke (3) shows the most important ions to be considered in any water analysis. (See Table 1)

TABLE 1.

Composition of Natural Waters

| | North America | World |
|---|---|---|
| $CO_3$ ........... | 33.40 | 35.15 |
| $SO_4$ ........... | 15.31 | 12.14 |
| Cl ........... | 7.44 | 5.68 |
| $NO_3$ ........... | 1.15 | 0.90 |
| Ca ........... | 19.39 | 20.39 |
| Mg ........... | 4.87 | 3.41 |
| Na ........... | 7.46 | 5.79 |
| K ........... | 1.77 | 2.12 |
| $(Fe, Al)_2O_3$ ... | 0.64 | 2.75 |
| $SiO_2$ .......... | 8.60 | 11.67 |
| | 100.00 | 100.00 |

Water rarely, if ever, exists in nature as pure $H_2O$. There is always a certain amount of carbon dioxide present in it. Rain falling through the atmosphere picks

up a small amount of carbon dioxide. In the soil, and in lakes and rivers, the decay of organic matter will release carbon dioxide. It is largely to the solvent power of carbonated waters that rivers and lakes owe their dissolved solids. Simple hydrolyses and solution also play an important part in adding to the solid contents of natural waters.

Since water carrying carbonic acid in solution is the primary agent of rock decomposition, it is an almost necessary inference that carbonates or bicarbonates should be the principal salts in nearly all fresh waters. A glance at the averages for North America and the world or any analysis of natural water will bear out this statement. The two chief sources of carbonates are the decompositions of feldspars and the solution of limestones. Table 2, as given by Clarke (32), shows the approximate mean mineral composition of igneous rocks, shales and sandstones.

TABLE 2.

Approximate Mean Mineral Composition of Igneous rocks, shales and sandstones

| Mineral | Igneous Rocks | Shales | Sandstones |
|---|---|---|---|
| Quartz .................... | 12.0 | 22.3 | 66.8 |
| Feldspars ................. | 59.5 | 30.0 | 11.5 |
| Clay ...................... |  | 25.0 | 6.6 |
| Hornblende and pyroxene ... | 16.8 |  |  |
| Mica ...................... | 3.8 |  |  |
| Limonite .................. |  | 5.6 | 1.8 |
| Carbonates ................ |  | 5.7 | 11.1 |
| Other minerals ............ | 7.9 | 11.4 | 2.2 |
|  | 100.0 | 100.0 | 100.0 |

A glance at this table reveals that quantitatively the feldspars are probably the most important group of minerals. They comprise several related chemical compounds of silica, alumina, with potash, soda and lime. They include (1) the potash feldspars, orthoclase and microcline ($KAlSi_3O_8$), (2) the soda feldspar, albite ($NaAlSi_3O_8$) and (3) the lime feldspar anorthite ($CaAl_2Si_2O_8$), (4) mixtures of (1) and (2), alkalic feldspar, and (5) mixtures of (2) and (3), plagioclase or soda-lime feldspars.

Clarke (3) gives the composition of feldspars as shown in Table 3.

TABLE 3.

Composition of Feldspars

| | Albite | Orthoclase | Anorthite |
|---|---|---|---|
| $SiO_2$ ..... | 68.7 | 64.7 | 43.2 |
| $Al_2O_3$ ..... | 19.5 | 18.4 | 36.7 |
| CaO ..... | - | - | 20.1 |
| $Na_2O$ ..... | 11.8 | - | - |
| $K_2O$ ..... | - | 16.9 | - |
| | 100.0 | 100.0 | 100.0 |

Calcium ranks first among the basic elements occuring in river waters. Its origin is probably mainly from limestones and dolomites. Limestones are largely $CaCO_3$ and dolomite has the formula $CaMg(CO_3)_2$. In the presence of carbonic acid limestone goes into solution as the bicarbonate.

$$CaCO_3 + H_2CO_3 = Ca(HCO_3)_2$$

The decomposition of the lime feldspar, anorthite, would be another important source of calcium. A possible equation expressing such decomposition is as follows:

$$2CaAl_2Si_2O_8 + 4H_2O + 2CO_2 = H_4Al_2Si_2O_9 \quad Al_2O_3.2SiO_2.H_2O + 2CaCO_3$$

Anorthite Kaolinite Clay

The calcium carbonate thus produced is further acted on by the carbonated waters. The solution of gypsum would be a source of both sulphate ions and calcium ions. A small amount of calcium may be derived from hornblende or pyroxene or from the ubiquitous apatite. Apatite would also be a source of phospate and flourine.

The solution of magnesium limestones and dolomite is probably the chief source of dissolved magnesium in natural waters, but the decomposition of amphiboles, pyroxenes and olivene is in some areas probably more important. Both calcium and magnesium occur in waters mainly as bicarbonate; this to some extent accounts for the relatively high bicarbonate ion content of rivers and lakes.

The alkaline elements, sodium and potassium, are derived from the alkaline feldspars, albite and orthoclase, as well as from salt beds of sedimentary deposits. Sedimentary rocks of marine origin often contain alkali salts. The decomposition of albite is represented by the equation:

$$2NaAlSi_3O_8 + CO_2 + H_2O = H_4Al_2Si_2O_9 + 4SiO_2 + Na_2CO_3$$

The sodium carbonate thus formed is very soluble in water.

Some authorities (31) emphasize the importance of hydrolysis in bringing about disintegration and solution. Under natural conditions carbonation, oxidation, hydrolysis

and simple solution will all play a part in the process. These changes are accompanied by an increase in bulk, thus tending to break up the containing rock to further disintegration. As an example of hydrolysis releasing a soluble alkali consider the decomposition of microcline feldspar. This mineral slowly reacts with water and produces a series of compounds. They may be represented by the following equations:

1. $KAlSi_3O_8 + H_2O = KOH + HAlSi_3O_8$
2. $HAlSi_3O_8 + H_2O = H_3AlSi_3O_9$
3. $H_3AlSi_3O_9 + H_2O = H_3AlSi_2O_7 + H_2SiO_3$
4. $H_3AlSi_3O_7 + H_2O = H_3AlSiO_5 + H_2SiO_3$
5. $H_2SiO_3 = H_2O + SiO_2$

The above reactions would also be a source of silica in waters. In the first equation Na may be substituted for K. Some sodium might come from syenites, and potassium from leucite rocks, but these would be of no general significance in irrigation waters of Alberta. Clarke (3) states that potassium is of minor significance, because much of it is retained by the sediments and does not find its way into the river waters.

Sulphates rank next to carbonates among the solid contents of river waters. Their original source was the oxidation and partial solution of iron pyrites. Pyrite is common in many rocks, where it is rather easily altered by oxidation, an example being as follows:

$$4FeS_2 + 11\ O_2 + 3H_2O = 2Fe_2O_3.3H_2O + 8SO_2.$$

The sulphur dioxide thus produced changes to sulphuric acid which vigorously attacks the rocks producing various soluble sulphates.

The sulphates are either disseminated in the soil or concentrated into beds of gypsum, etc. Drainage from coal mines often contains sulphates. Certain industries such as pulp and paper mills cause pollution of streams with sulphates and other compounds. In farming areas where mineral fertilizers are extensively used, there may be a local influence on the composition of both ground and surface waters. Fertilizers containing gypsum or superphosphates may yield sulphates to adjacent waters. Such an influence would be mainly apparent in seepage from the banks of a stream.

Only a very small part of the chlorides contained in river waters can be traced to the immediate decomposition of igneous rocks. Nearly all of it is primarily derived from marine rocks and sediments; some may come from sewage. The sedimentary rocks, especially those of marine origin, commonly contain at least traces of chlorides, and such deposits as those of rock salt are composed almost entirely of them. Where beds of salt exist they affect the springs which pour their dissolved salts into the streams. Salt also accumulates in arid soils and from them is leached into rivers and streams.

Sewage from cities sometimes contains appreciable amounts of chlorides. Clarke (3) points out the influence of the Chicago drainage canal upon the Illinois and Mississippi rivers. The canal causes quite an increase in the chloride content of the Illinois river with a gradual diminution downstream. There is a drop of 10 p.p.m. of chloride when the Illinois River enters the Mississipp i. This is due to dilution. Oil wells are often the source of chloride. Petroleum is commonly accompanied by strong

brines which are brought to the surface and allowed to drain away when wells are drilled.

The silica content of river waters may be derived from the solution of almost any rock forming silicates, except probably those contained in shales and slates, which, with sandstone, represent the end products of aqueous decomposition. The chief source of silicas is from feldspars. The decomposition of feldspars has been referred to on page 17. Another source of silica would be the hydrolyses of certain silicates, for example, calcium silicate:

$$CaSiO_3 + 2H_2O = Ca(OH)_2 + H_2SiO_3$$

Although the determination of silica is often neglected it is one of the most significant constituents of river and lake waters. The chief source of silica is from the feldspars and a glance at Table 3 will show that albite and orthoclase yield more silica to waters than anorthite. Clarke (3) states that if the silica in the anhydrous residue from a water exceeds 30 percent the alkali feldspars are probably in excess of the lime feldspars. A low silica would indicate a predominance of anorthite and other minerals. Besides being of some aid in diagnosis of parent minerals of solids in waters, silica serves as a cement which binds grains of sand together and so helps to form sandstone.

Nitrates are usually of minor significance. They may be formed together with ammonia, by electrical discharges in the atmosphere and then brought to the surface of the earth in rain. Other sources are sewage, drainage from fertilized fields or

even barnyards. An occasional mineral spring might contain nitrates. The above sources to most natural waters are of little significance.

Sesquioxides of iron and aluminum are almost invariably present in river water but rarely in large amounts. A high value usually indicates failure to remove all the suspended material before running the determination. Very finely divided sediments are easily retained in suspension and appear in the analyses.

Of the minor constituents, phosphate is the most important. Traces of phosphates are usually common, but overlooked. They are derived from apatite of the igneous rocks and from sedimentary deposits. Waters flowing over an area containing beds of phosphate rock are likely to contain more than traces. Boron, manganese, zinc, etc., are sometimes found in waters but are of very local occurrence.

Organic matter is almost universally present. It is derived from the decay of vegetation, or may represent pollution by sewage. As previously pointed out, it is the chief source of carbonic acid.

## MATERIALS

### Soil Samples

In the first week of September, 1939, two sets of soil samples were collected at the Dominion Experimental Farm, Lethbridge, Alberta, by Dr. F. A. Wyatt, Mr. W. E. Bowser,

and Mr. Wm. Odynsky. One set was taken from an irrigated area and the other from virgin dry land. The samples from the irrigated land were taken about one hundred yards east of the main irrigation ditch in plot 6 of rotation X, which is a rotation involving wheat, oats, barley, corn, peas, and alfalfa. Alfalfa was growing in plot 6 when the samples were collected. The area had been under irrigation for approximately twenty-five years. Five holes were dug with a shovel within a radius of nine feet and to a depth of about two feet. Three of the holes were dug to a depth of 54 inches. The samples were taken at the various depths in duplicate, from opposite sides of the holes and at the same depth in the different holes. About equal sized samples were taken from the holes and then bulked in respective bags. The top samples are composites from five holes and the bottom samples are composites from only three holes.

The following description of the samples was made at the time of collection:

| Sample No. | Depth | Description |
|---|---|---|
| 151 N.<br>&<br>152 S. | 0"- 8" | Heavy loam; silty but containing very fine sand. Puddled (heavy to plow depth). Aggregates readily break down on the addition of water. |
| 153 N.<br>&<br>154 S. | 8"-14" | Heavy loam to clay loam; fine sand and clay; very little organic matter. Soil quite columnar, limy; light brown color. |
| 155 N.<br>&<br>156 S. | 14"-19" | Clay loam; uniform, fine sand and clay. Columnar, limy; brown color. |
| 157 N.<br>&<br>158 S. | 19"-28" | Heavy loam; fine sand and clay. A lighter colored layer in the upper 3 or 4 inches. |

| Sample No. | Depth | Description |
|---|---|---|
| 159 N.<br>&<br>160 S. | 28"-38" | Clay loam; sand and clay. |
| 161 N.<br>&<br>162 S. | 38"-44" | Heavy loam; very sandy. Quite dark in color. |
| 163 N.<br>&<br>164 S. | 44"-54" | Heavy loam; very sandy. |

The same method of sampling was used on the non-irrigated soil as was used on the irrigated. The samples were taken from holes dug along a road cut about 160 yards west of the previous samples and in line with, but a little southwest of, the other series. The main irrigation canal runs about 60 yards east of this location. The land has never been cultivated or irrigated. It has about the same elevation as the land where the irrigated samples were taken. The soil was classified at the different depths as follows:

| Sample No. | Depth | Class |
|---|---|---|
| 165 N.<br>&<br>166 S. | 0"- 8" | Heavy loam; silty but containing fine sand. Contains more organic matter than the surface 8 inches of the irrigated land. Aggregates break down quite easily with the addition of water. |
| 169 N.<br>&<br>170 S. | 14"-19" | Clay loam. |
| 171 N.<br>&<br>172 S. | 19"-28" | Clay loam; sandy. |
| 173 N.<br>&<br>174 S. | 28"-38" | Heavy loam to clay loam; sandy. |

| Sample No. | Depth | Class |
|---|---|---|
| 175 N.<br>&<br>176 S. | 38"-44" | Heavy clay loam; sandy. |
| 177 N.<br>&<br>178 S. | 44"-54" | Clay. |

It will be noted that this profile is heavier in the lower depths than the irrigated profile. Free percolation of water in the sandy subsoil of the irrigated land would result in leaching of salts.

## Water Samples

Irrigation water samples were collected during the irrigation season of the year 1941. Four sets,of ten each, of clean Winchester bottles consecutively numbered were sent out from the Soils Laboratory to four different locations in the irrigated areas of southern Alberta. The bottles were provided with tightly fitting rubber stoppers and a means of tying the stoppers firmly in the bottles when filled, so as to prevent any evaporation between time of collecting and analyzing the samples. Water samples were collected at approximately weekly intervals for the first three weeks and thereafter at intervals of about two weeks. Each bottle was labelled at the time of collection with the date and location.

The first two sets of bottles, numbered 1 to 20, were sent to Mr. L. C. Charlesworth, Manager of the Eastern

Irrigation District, Brooks, Alberta. One set of samples, numbered 1 to 10, was taken from Lake Newell, which is a large reservoir of the E. I. D. system. It is located about six miles south of the town of Brooks. The other set of samples, numbered 21 to 30, was collected by Mr. Hargraves from a canal near the town of Brooks.

The third set of bottles, numbered from 21 to 30 consecutively, was sent to Mr. Clendennan at Lethbridge, Alberta. The samples were collected from a canal of the Lethbridge Northern Irrigation District near the town of Picture Butte.

The fourth set of bottles, numbered 31 to 40, was sent to the Dominion Experimental Farm at Lethbridge, Alberta. Mr. Charles Walkof collected the samples. The first eight samples, 31 to 38, were taken from a lateral which runs by the office of the Experimental Farm. The last two samples, 39 and 40, were taken from the main canal at a point north and west of the office and less than a quarter of a mile away.

All four sets of bottles were returned to the laboratory late in September, 1941. Analyses were not started till the third week in January, 1942, so that the possibility of some slight reaction with the bottles, or of bacterial action in the bottles, must be taken into consideration. The samples collected in the spring of the year remained stoppered for six to seven months while those collected in the fall of the year remained stoppered for about only four months. The intervening samples thus remained stoppered from four to six months.

## METHODS

### Soil Analyses

The soil samples collected at the Lethbridge Experimental Farm were analyzed for inorganic carbon using a "Parr" carbon apparatus. The volume of $CO_2$ released from a known quantity of soil, on the addition of dilute hydrochloric acid was measured by difference in volume before and after absorption of the $CO_2$ in concentrated sodium hydroxide solution. The volume of $CO_2$ thus obtained was then calculated in terms of carbon, calcium carbonate and from the latter calcium was calculated.

Total calcium was determined on the samples. A sodium peroxide fusion was made. The melt was taken up with water and then dehydrated to dehydrate the silica. The residue was taken up with HCl and diluted. Iron and aluminum were precipitated as hydroxides and filtered off along with the silica. The calcium was then precipitated as the oxalate and filtered off. The oxalate was dissolved in concentrated sulphuric acid. The oxalic acid released was then titrated while hot with standard potassium permanganate solution.

Water soluble salts were determined on the samples. A one to five ratio of soil to water was employed and the mixture shaken for 20 minutes, allowed to stand for a few minutes, and then filtered through a Berkfeld filter. The methods used to determine the total solids, non-volatile solids

and the ions present in the filtrate are essentially the same as those used in the water analyses which follow. The ions are expressed in percent of soil weight. Each analysis was done in duplicate, and with two samples for each of the various depths four results were obtained. The results reported in Table 9 are the averages of the four results.

## Water Analyses

### Suspended Material

Suspended material was determined only on the samples from Lethbridge. After thoroughly shaking a sample to obtain complete mixing and even distribution of the suspended material, 50 cc. were drawn off with a pipette, and transferred to a weighed evaporating dish. When this had evaporated, the process was repeated so that the total volume evaporated in each case was 100 cc. (In using a pipette for drawing off aliquots of sample, the tip was always placed well down in the bottle.) The evaporation of the sample was carried out in an electric oven at 110°C. After weighing the residue which represented suspended material and total dissolved solids, it was heated to 700°C. in an electric furnace. The residue after fusing is non-volatile suspended material and non-volatile dissolved solids. The value for suspended material and non-volatile suspended material is obtained by subtraction. Suspended material and dissolved solids are expressed in parts per million and in pounds per acre foot. One acre foot of water for purposes of calculation is assumed to weigh 2,720,000 pounds.

Then, parts per million x 2.72 = pounds per acre foot,
or, parts per million x 0.00136 = tons per acre foot.

## Dissolved Solids

Four hundred cc. of sample were evaporated to dryness in a weighed evaporating dish on the steam bath, the sample being added with a pipette in 50 cc. portions of clear supernatant solution till a volume of 400 cc. had been evaporated. The final drying was carried out in the electric oven at 110°C. for about 8 hours. After cooling and weighing total solids, the non-volatile dissolved solids were determined by heating in the electric furnace to 700°C., cooling and weighing.

## Calcium and Magnesium

The residue of non-volatile solids was carefully extracted with dilute hydrochloric acid. One cc. of concentrated acid and 10 cc. of distilled water were added to each crucible. The crucibles were then covered with a watch glass and placed on the steam bath for about 20 minutes. The solution of salts was carefully transferred to 250 cc. beakers using a wash bottle with hot water and policeman to make sure that all the residue was removed from the crucibles. Two cc. of concentrated acid were then added to the crucibles, rotating to wet all the inside surface of the dish, and the process of extraction repeated.

Calcium was determined by the usual oxalate precipitation and permanganate titration method. Magnesium was determined

on the filtrate from the calcium determination. The method as used in Rubidoux Laboratory, Riverside, California (23) was followed except that the precipitate was not burned off to magnesium pyrophosphate. Instead the precipitate was dried over night at room temperature, dissolved in excess standard sulphuric acid, and then titrated with standard sodium hydroxide, using brome cresol green as the indicator.

## Carbonate, Bicarbonate and Chloride

The method used to determine carbonate and bicarbonate was essentially the same as used in Rubidoux Laboratory, Riverside, California, except that 0.02 normal sulphuric acid was used instead of 0.05 normal sulphuric acid. The method used for chloride was identical.

## Sulphate

The same method that is used in Rubidoux Laboratory was used to determine sulphate.

## Iron

Iron was not determined on all samples. In the calcium determination the iron and aluminum were precipitated and filtered off, and in every case the precipitate was almost negligible. The amount of iron in the precipitate from samples 21 to 25 was determined by the method given in Standard Methods of Water Analyses and other sources (4, 23, 32). The iron content ranged from 0.04 parts per million to 0.08 parts per

million. It was estimated from close observation on all samples that the iron present in any one sample would not exceed 0.1 parts per million.

## Sodium and Potassium

Sodium and potassium were not determined analytically. A value for sodium plus potassium was obtained by subtraction. The sum of the equivalents per million of the anions minus the sum for calcium and magnesium also in equivalents per million gives a number which closely approximates the sodium content when multiplied by 23 (to change it to parts per million). Potassium content of most waters is small so that the error involved by this method is almost negligible with respect to potassium. It includes, however, the algebraic sum of all the errors in the determination of the acid radicles and of calcium and magnesium. In referring to the agreement of analyses, the following statement is taken from American Public Health Association, 1936, Standard Methods for the Examinations of Water and Sewage, Ed. 8, New York, and quoted in Methods of Analyses used in the Rubidoux Laboratory, Riverside, California. "The sum of the milli-equivalent of basic radicles must obviously equal the sum of the milli-equivalents of acid radicles. In routine practice a variation from 15 percent in waters of less than 50 p.p.m. residue down to 2 percent variation in waters of over 1000 p.p.m. residue may be expected."

## Hydrogen Ion Concentration

The hydrogen ion concentration of the samples was determined with a Beckman pH meter.

## Results

The results of the analyses are summarized in Tables 4 to 9. Two methods of expressing the results of the ion determinations are used, viz.: parts per million, and equivalents per million. The latter expression is the same as milligram equivalents per kilogram or reacting values. Equivalents per million are obtained by dividing the values obtained for parts per million by the equivalent weights of the ions concerned. To simplify the operation parts per million was multiplied by the reciprocals of the equivalent weights, as suggested by Collins (4).

Other tables reported were obtained from various sources. Numbers 10 and 11 were obtained from Mr. James Younge, City Chemist, Calgary, Alberta. Tables 12 and 15 were obtained from Mr. W. Crook, Engineer for the Eastern Irrigation District, Brooks, Alberta; Table 13 was obtained from Mr. J. A. Kelso, Provincial Analyst, University of Alberta, Edmonton. Table 14 is a summary of analyses carried out by the Department of Soils, University of Alberta.

The following abbreviations are used in the tables:

T.D.S. - Total dissolved solids
lb./a.f. - Pounds per acre foot
N.v.D.S. - Non-volatile dissolved solids

## [illegible]

[illegible]

## [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

L.I. - Loss on ignition

S.M. - Suspended material

N.v.S.M. - Non-volatile suspended material

T.S. - Total solids

N.V.S. - Non-volatile solids

p.p.m. - Parts per million

E.p.m. - Equivalents per million

T. - Trace

0.0 - Determination completed but none of the ion present.

--- - Determination not carried out, or not reported.

## DISCUSSION OF RESULTS

Table 4 shows a summary of the analyses of irrigation water from Lake Newell. The salt content is fairly uniform throughout the irrigation season. The first two samples are very much alike and 20 p.p.m. or more higher in total dissolved solids than any of the later samples in the table. There appears to be a gradual decrease in dissolved solids throughout the irrigation season. The differences in the ions determined are, however, very small. Calcium varies only about 6 parts per million, magnesium varies 3 p.p.m., sulphate 10 p.p.m., and bicarbonate 29 p.p.m. Such variations are to be expected.

It will be noted that no value for sodium is reported for samples 4, 8 and 10; this is due to a negative value

TABLE 4

## SUMMARY OF ANALYSES OF LAKE NEWELL IRRIGATION WATER COLLECTED DURING THE IRRIGATION SEASON, 1941

| Bottle No.<br>Date collected | 1<br>June<br>5 | 2<br>June<br>12 | 3<br>June<br>19 | 4<br>June<br>26 | 5<br>July<br>10 | 6<br>July<br>24 | 7<br>Aug.<br>7 | 8<br>Aug.<br>21 | 9<br>Sept.<br>4 | 10<br>Sept.<br>18 |
|---|---|---|---|---|---|---|---|---|---|---|
| Dissolved solids | | | | | | | | | | |
| T.D.S., p.p.m. | 223 | 227 | 202 | 201 | 202 | 194 | 198 | 191 | 195 | 184 |
| T.D.S., lb./a.f. | 607 | 617 | 548 | 545 | 548 | 528 | 539 | 520 | 530 | 500 |
| N.v.D.S., p.p.m. | 160 | 165 | 133 | 144 | 142 | 136 | 143 | 137 | 138 | 126 |
| N.v.D.S., lb./a.f. | 435 | 449 | 360 | 392 | 385 | 369 | 388 | 373 | 375 | 343 |
| L.I., p.p.m. | 63 | 62 | 69 | 57 | 60 | 48 | 56 | 54 | 57 | 58 |
| Mineral Analyses--ions expressed in parts per million | | | | | | | | | | |
| pH value | 8.4 | 7.9 | 6.9 | 7.4 | 7.7 | 7.4 | 7.9 | 7.0 | 7.1 | 7.8 |
| Ca, p.p.m. | 42.7 | 43.2 | 40.1 | 40.1 | 39.1 | 37.8 | 36.5 | 37.1 | 36.8 | 36.8 |
| Mg, p.p.m. | 18.3 | 17.0 | 15.1 | 16.7 | 15.1 | 15.4 | 14.4 | 16.0 | 16.0 | 16.0 |
| Na + K (diff.), p.p.m. | 4.6 | 1.1 | 3.7 | --- | 0.7 | 1.1 | 2.8 | --- | 0.5 | --- |
| $SO_4$, p.p.m. | 45.0 | 46.5 | 44.0 | 42.0 | 39.5 | 42.0 | 42.0 | 49.3 | 47.1 | 41.4 |
| $HCO_3$, p.p.m. | 148.8 | 161.0 | 151.3 | 148.1 | 146.4 | 142.7 | 136.6 | 129.3 | 134.2 | 136.6 |
| $CO_3$, p.p.m. | 13.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cl, p.p.m. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Fe, p.p.m. | *∠0.1 | ∠0.1 | ∠0.1 | ∠0.1 | ∠0.1 | ∠0.1 | ∠0.1 | ∠0.1 | ∠0.1 | ∠0.1 |
| Reacting values = equivalents per million | | | | | | | | | | |
| Ca, E.p.m. | 2.13 | 2.16 | 2.00 | 2.00 | 1.95 | 1.89 | 1.82 | 1.85 | 1.84 | 1.84 |
| Mg, E.p.m. | 1.50 | 1.40 | 1.24 | 1.37 | 1.24 | 1.27 | 1.17 | 1.32 | 1.32 | 1.32 |
| Na + K (diff.), p.p.m. | 0.20 | 0.05 | 0.16 | ---- | 0.03 | 0.05 | 0.12 | ---- | 0.02 | ---- |
| $SO_4$, E.p.m. | 0.94 | 0.97 | 0.92 | 0.87 | 0.82 | 0.87 | 0.87 | 1.03 | 0.98 | 0.86 |
| $HCO_3$, E.p.m. | 2.44 | 2.64 | 2.48 | 2.43 | 2.40 | 2.34 | 2.24 | 2.12 | 2.20 | 2.24 |
| $CO_3$, E.p.m. | 0.45 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

* Fe estimated.

obtained by subtraction when arriving at the value for sodium as previously explained. However, the values for sodium for the other samples are all within experimental error.

Table 5 shows the results of analyses of irrigation water collected at Brooks. While they are not complete, due to the loss of two samples, the results give a fair picture of salt content for the irrigation season. There is greater variation in salt content than in the case of Lake Newell water. Calcium varies from 46 p.p.m. to 35 p.p.m. while magnesium ranges from 11 to 14 p.p.m. and sulphate varies from 52 down to 31 p.p.m. Bicarbonate has the greatest variation, from 130 to 173 p.p.m.

A negative value for Na + K was obtained for samples 13 and 18. Samples 11 and 19 would likely contain more than traces of sodium, but the others are within the experimental error.

Since the water was obtained from a secondary canal, greater variation in salt content is to be expected. Main irrigation canals usually follow high land and there is a tendency towards seepage from the canals rather than a water movement into them. Instead of more salts being dissolved there would likely be a tendency for the salt content of the water to remain more or less similar to the parent source, that is, over a reasonable distance from the parent source. From a comparison of Table 10 and Table 4, it would appear that Lake Newell contains even less salts than the parent source. However, the analyses were not made in the same year so that such a comparison

TABLE 5

SUMMARY OF ANALYSES OF IRRIGATION WATER COLLECTED AT BROOKS DURING THE IRRIGATION SEASON, 1941

| Bottle No.<br>Date Collected | 11<br>June 5 | 12<br>June 12 | 13<br>June 19 | 14<br>June 26 | 15<br>July 10 | 16<br>July 24 | 17<br>Aug. 7 | 18<br>Aug. 21 | 19<br>Sept. 4 | 20<br>Sept. 18 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Dissolved solids** | | | | | | | | | | |
| T.D.S., p.p.m. | 301 | 278 | 182 | Broken in transit | 213 | 169 | Broken in transit | 174 | 169 | 192 |
| T.D.S., lb./a.f. | 819 | 756 | 495 | | 580 | 459 | | 473 | 460 | 523 |
| N.v.D.S., p.p.m. | 235 | 223 | 131 | | 161 | 124 | | 125 | 118 | 138 |
| N.v.D.S., lb./a.f. | 639 | 607 | 357 | | 437 | 337 | | 339 | 321 | 377 |
| L.I., p.p.m. | 66 | 55 | 51 | | 52 | 45 | | 49 | 51 | 54 |
| **Mineral analyses--Ions expressed in parts per million** | | | | | | | | | | |
| pH value | 8.2 | 8.0 | 8.2 | | 7.7 | 7.9 | | 7.7 | 8.0 | 8.1 |
| Ca, p.p.m. | 46.0 | 45.7 | 39.2 | | 39.5 | 35.8 | | 37.1 | 35.3 | 37.8 |
| Mg, p.p.m. | 13.9 | 12.6 | 13.0 | | 12.2 | 12.9 | | 12.3 | 11.3 | 12.3 |
| Na + K (diff.), p.p.m. | 11.5 | 5.7 | -- | | 2.8 | 0.5 | | -- | 9.9 | 3.9 |
| $SO_4$, p.p.m. | 52.5 | 51.7 | 35.0 | | 39.0 | 34.0 | | 31.2 | 33.5 | 41.0 |
| $HCO_3$, p.p.m. | 173.2 | 152.0 | 120.0 | | 139.0 | 132.0 | | 133.0 | 139.0 | 130.0 |
| $CO_3$, p.p.m. | 0.0 | 0.0 | 7.2 | | 0.0 | 0.0 | | 0.0 | 4.1 | 2.4 |
| Cl, p.p.m. | 0.0 | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | 0.0 |
| Fe, p.p.m. | *∠0.1 | ∠0.1 | ∠0.1 | | ∠0.1 | ∠0.1 | | ∠0.1 | ∠0.1 | ∠0.1 |
| **Reacting values = equivalents per million** | | | | | | | | | | |
| Ca, E.p.m. | 2.29 | 2.28 | 1.96 | | 1.97 | 1.79 | | 1.85 | 1.76 | 1.89 |
| Mg, E.p.m. | 1.14 | 1.04 | 1.07 | | 1.00 | 1.06 | | 1.01 | 0.93 | 1.01 |
| Na + K (diff.), p.p.m. | 0.50 | 0.25 | -- | | 0.12 | 0.02 | | -- | 0.43 | 0.17 |
| $SO_4$, E.p.m. | 1.09 | 1.08 | 0.73 | | 0.81 | 0.71 | | 0.65 | 0.70 | 0.85 |
| $HCO_3$, E.p.m. | 2.84 | 2.49 | 1.97 | | 2.28 | 2.16 | | 2.18 | 2.28 | 2.14 |
| $CO_3$ | 0.0 | 0.0 | 0.24 | | 0.0 | 0.0 | | 0.0 | 0.14 | 0.08 |

* Fe estimated.

is of little value. Precipitation of any of the salt from the water in Lake Newell is very unlikely because the water contains relatively small amounts of salt.

Table 6 shows the analyses of water collected at Picture Butte. There is a greater variation in salt content over the time of collection than is found in any of the other analyses. Calcium varies from 42 p.p.m. down to 22 p.p.m. and magnesium from 14.8 to 11.3 p.p.m. The sulphate content varies to 110 p.p.m. It will be noted that this water has lower average salt content than is found in Brooks or Lake Newell waters. The lower sulphate content is the most striking. The average sulphate content for Lake Newell is 44 p.p.m., for Brooks 40 p.p.m., and for Picture Butte it is only 26 p.p.m. The average calcium content, 32 p.p.m., is lower than Lake Newell or Brooks, both of which contain an average of 40 p.p.m. of calcium. The average bicarbonate is a little higher than found in Lake Newell and Brooks waters. The values obtained for sodium indicated that there might be small amounts of sodium present. There would be more than traces in samples 21, 25, 26, 28 and 29.

Table 7 shows the analyses of irrigation water from Lethbridge. The first part of the table shows the suspended material. There is considerable variation throughout the irrigation season. Regarding the amount of suspended material in rivers at different times of the year Widtsoe makes the following statement:

"The quantity of suspended material in a river will vary considerably throughout the year. When the lands around the head waters of the rivers are not covered with snow and

TABLE 6

## SUMMARY OF ANALYSES OF IRRIGATION WATER COLLECTED AT PICTURE BUTTE DURING THE IRRIGATION SEASON, 1941

| Bottle No.<br>Date collected | 21<br>May<br>16 | 22<br>May<br>23 | 23<br>May<br>30 | 24<br>June<br>13 | 25<br>June<br>27 | 26<br>July<br>11 | 27<br>July<br>25 | 28<br>Aug.<br>8 | 29<br>Aug.<br>22 | 30<br>Sept.<br>5 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Dissolved solids** | | | | | | | | | | |
| T.D.S., p.p.m. | 205 | 220 | 221 | 173 | 187 | 175 | 154 | 172 | 174 | 138 |
| T.D.S., lb./a.f. | 558 | 597 | 600 | 469 | 509 | 475 | 419 | 468 | 473 | 375 |
| N.v.D.S., p.p.m. | 146 | 157 | 164 | 118 | 131 | 127 | 109 | 127 | 132 | 94 |
| N.v.D.S., lb./a.f. | 398 | 462 | 446 | 321 | 356 | 345 | 296 | 344 | 358 | 255 |
| L.I., p.p.m. | 59 | 63 | 57 | 55 | 56 | 48 | 45 | 46 | 43 | 44 |
| **Mineral analyses--ions expressed in parts per million** | | | | | | | | | | |
| pH value | 7.5 | 7.6 | 7.7 | 8.2 | 7.2 | 7.8 | 7.9 | 7.9 | 8.2 | 7.4 |
| Ca, p.p.m. | 40.6 | 42.3 | 40.1 | 36.1 | 38.8 | 29.3 | 26.1 | 23.1 | 22.0 | 23.5 |
| Mg, p.p.m. | 14.8 | 14.5 | 13.9 | 14.2 | 14.5 | 13.5 | 13.5 | 12.9 | 11.3 | 13.2 |
| Na + K (diff.), p.p.m. | 17.2 | 6.4 | 4.6 | 6.4 | 8.5 | 10.4 | 6.7 | 8.5 | 10.1 | 3.7 |
| $SO_4$, p.p.m. | 27.5 | 27.0 | 26.0 | 24.5 | 28.0 | 26.0 | 26.0 | 25.8 | 24.6 | 26.0 |
| $HCO_3$, p.p.m. | 209.4 | 184.2 | 171.0 | 159.8 | 178.1 | 151.3 | 131.8 | 124.4 | 109.8 | 114.7 |
| $CO_3$, p.p.m. | 0.0 | 0.0 | 0.0 | 3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 4.8 | 0.0 |
| Cl, p.p.m. | 0.0 | 0.0 | T. | 0.0 | T. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Fe, p.p.m. | *∠0.1 | ∠0.1 | ∠0.1 | ∠0.1 | ∠0.1 | ∠0.1 | ∠0.1 | ∠0.1 | ∠0.1 | ∠0.1 |
| **Reacting values = equivalents per million** | | | | | | | | | | |
| Ca, E.p.m. | 2.03 | 2.11 | 2.00 | 1.80 | 1.94 | 1.46 | 1.30 | 1.15 | 1.10 | 1.17 |
| Mg, E.p.m. | 1.22 | 1.19 | 1.14 | 1.17 | 1.19 | 1.11 | 1.11 | 1.06 | 0.93 | 1.09 |
| Na + K (diff.), E.p.m. | 0.75 | 0.28 | 0.20 | 0.28 | 0.37 | 0.45 | 0.29 | 0.37 | 0.44 | 0.16 |
| $SO_4$, E.p.m. | 0.57 | 0.56 | 0.54 | 0.51 | 0.58 | 0.54 | 0.54 | 0.54 | 0.51 | 0.54 |
| $HCO_3$, E.p.m. | 3.43 | 3.02 | 2.80 | 2.62 | 2.92 | 2.48 | 2.16 | 2.04 | 1.80 | 1.88 |
| $CO_3$, E.p.m. | 0.0 | 0.0 | 0.0 | 0.12 | 0.0 | 0.0 | 0.0 | 0.0 | 1.60 | 0.0 |
| Cl, E.p.m. | 0.0 | 0.0 | 0.0 | 0.0 | T. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

* Fe estimated

## TABLE 7

### SUMMARY OF ANALYSES OF IRRIGATION WATER COLLECTED AT LETHBRIDGE EXPERIMENTAL STATION DURING THE IRRIGATION SEASON, 1941

| Bottle No. | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 |
|---|---|---|---|---|---|---|---|---|---|---|
| Date collected | May 12 | May 19 | May 26 | June 13 | June 23 | July 9 | July 24 | Aug.6 | Aug.21 | Sept.4 |
| Suspended material and dissolved solids | | | | | | | | | | |
| S.M. + T.D.S., p.p.m. | 1341 | 1151 | 582 | 2467 | 504 | 1028 | 400 | 217 | 177 | 181 |
| S.M. + T.D.S., lb./a.f. | 3648 | 3131 | 1583 | 6710 | 1371 | 2796 | 1088 | 590 | 481 | 492 |
| S.M., p.p.m. | 1204 | 1027 | 440 | 2262 | 384 | 878 | 269 | 80 | 64 | 60 |
| S.M., lb./a.f. | 3275 | 2793 | 1196 | 6152 | 1044 | 2388 | 732 | 217 | 174 | 163 |
| N.v.S.M. & D.S., p.p.m. | 1178 | 1006 | 486 | 2135 | 414 | 889 | 331 | 161 | 128 | 123 |
| N.v.S.M. & D.S., lb./a.f. | 3205 | 2736 | 1322 | 5807 | 1126 | 2418 | 900 | 438 | 349 | 335 |
| N.v.S.M., p.p.m. | 1076 | 913 | 384 | 2066 | 327 | 779 | 240 | 61 | 29 | 46 |
| N.v.S.M., lb./a.f. | 2927 | 2532 | 1045 | 5619 | 889 | 2119 | 653 | 166 | 79 | 125 |
| L.I. of S.M. & T.D.S., p.p.m. | 163 | 145 | 96 | 332 | 90 | 139 | 69 | 56 | 49 | 58 |
| Dissolved solids | | | | | | | | | | |
| T.D.S., p.p.m. | 137 | 124 | 142 | 205 | 120 | 149 | 131 | 137 | 113 | 121 |
| T.D.S., lb./a.f. | 373 | 336 | 387 | 558 | 327 | 405 | 356 | 373 | 307 | 330 |
| N.v.D.S., p.p.m. | 102 | 93 | 102 | 169 | 87 | 110 | 91 | 100 | 99 | 77 |
| N.v.D.S., lb./a.f. | 276 | 252 | 277 | 460 | 237 | 301 | 247 | 272 | 269 | 209 |
| L.I. of T.D.S., p.p.m. | 35 | 31 | 40 | 36 | 33 | 39 | 40 | 37 | 14 | 44 |

TABLE 7 (continued)

| Bottle No.<br>Date collected | 31<br>May 12 | 32<br>May 19 | 33<br>May 26 | 34<br>June 13 | 35<br>June 23 | 36<br>July 9 | 37<br>July 24 | 38<br>Aug.6 | 39<br>Aug.21 | 40<br>Sept.4 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Mineral analyses--ions expressed in parts per million** | | | | | | | | | | |
| pH value | 8.5 | 8.1 | 7.7 | 7.4 | 8.0 | 8.0 | 7.5 | 7.6 | 8.2 | 7.6 |
| Ca, p.p.m. | 24.5 | 25.5 | 31.6 | 45.6 | 27.1 | 26.6 | 28.1 | 24.8 | 24.8 | 27.1 |
| Mg, p.p.m. | 9.5 | 9.8 | 9.5 | 11.6 | 9.5 | 6.9 | 8.5 | 7.3 | 9.8 | 10.4 |
| Na + K (diff.), p.p.m. | 2.8 | 1.2 | 0.7 | 2.5 | --- | 10.6 | 2.5 | 4.0 | 2.5 | 2.8 |
| $SO_4$, p.p.m. | 10.8 | 11.7 | 12.7 | 15.7 | 11.0 | 12.0 | 15.0 | 10.5 | 11.0 | 15.2 |
| $HCO_3$, p.p.m. | 101.3 | 114.7 | 123.2 | 183.0 | 112.2 | 126.9 | 115.9 | 114.7 | 117.1 | 122.0 |
| $CO_3$, p.p.m. | 7.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cl, p.p.m. | 0.0 | T. | 4.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Fe | *<0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| **Reacting values = equivalents per million** | | | | | | | | | | |
| Ca, E.p.m. | 1.22 | 1.27 | 1.58 | 2.27 | 1.35 | 1.30 | 1.40 | 1.24 | 1.24 | 1.35 |
| Mg | 0.78 | 0.80 | 0.78 | 0.95 | 0.78 | 0.57 | 0.70 | 0.60 | 0.80 | 0.85 |
| Na + K (diff.) | 0.12 | 0.05 | 0.03 | 0.11 | -- | 0.46 | 0.11 | 0.26 | 0.11 | 0.12 |
| $SO_4$ | 0.22 | 0.24 | 0.26 | 0.33 | 0.23 | 0.25 | 0.31 | 0.22 | 0.23 | 0.32 |
| $HCO_3$ | 1.66 | 1.88 | 2.02 | 3.00 | 1.84 | 2.08 | 1.90 | 1.88 | 1.92 | 2.00 |
| $CO_3$ | 0.24 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cl | 0.0 | T. | 0.11 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

* Fe estimated.

ice, the quantity of suspended matter carried by a river varies directly with the time and quantity of precipitation. A sudden flood will render the river waters turbid with suspended matter and the longer seasonal floods of spring and fall are characterized by long periods of muddy water."

The amount of suspended material in the irrigation water depends on: (1) the amount in the original stream, and (2) the volume of water allowed to flow in the ditches. Mr. Walkof states that at Lethbridge there is always considerable material carried in the ditches in the spring of the year. The spring flow usually runs at its heaviest during the middle of June, and accordingly all canals are filled to capacity, resulting in a heavy silt load. This undoubtedly accounts for the high figure for suspended material in sample 34, June 13. The lower value for sample 33 might be due to less water being required in the canals or to a natural fluctuation. The same might be said of sample 35.

The amount of water allowed to flow through the canals in the fall of the year is very much reduced and hence the rate of flow is also reduced; the water is not nearly as turbulent and does not carry as much suspended material as in the spring. The September flow at Lethbridge is about one-tenth that of the June flow. These facts would account for the very low figures for suspended material towards the end of the irrigation season. Judging by its appearance in the bottles the order of decreasing suspended material would be as follows: Lethbridge, Picture Butte, Brooks, and Lake Newell. The Lake Newell

samples contained only very slight amounts. There would likely be some settling out of suspended material in the lake.

It should be pointed out that a value, such as a ton or more of suspended material per acre foot for an irrigation ditch, does not necessarily mean that this amount will actually be carried to and deposited on the land. Silt originating in the river water is deposited to some extent along the ditches, necessitating cleaning of the ditches once every year, or even more often in some areas. The ditches at Lethbridge silt up very quickly in the spring of the year. The water in the laterals, being more turbulent, often contains more suspended material than in the larger canals.

The salt content of the water during the irrigation season did not vary very much, except for sample 34 which shows a higher salt content than any of the others. The loss on ignition of the suspended material and dissolved solids is some indication of the organic matter content. For sample 34 a value of 332 p.p.m. was obtained. The decay of organic matter is to some extent responsible for the bicarbonate and carbonate content of water. A negative value was obtained for sodium for sample 35. The sodium content of all but sample 36 is of doubtful significance. It will be noted that suspended material and total dissolved solids are lower in the last two samples, but there is actually very little difference in the ion content as compared to the other samples. It was previously pointed out that these samples were taken from the main canal.

Table 8 gives the averages of analyses from the four locations.

Table 8. Averages of water analyses

| | Lake Newell | Brooks | Picture Butte | Lethbridge |
|---|---|---|---|---|
| T.D.S., p.p.m. | 202 | 210 | 182 | 130 |
| N.v.D.S., p.p.m. | 142 | 157 | 130 | 96 |
| L.I., p.p.m. | 58 | 53 | 51 | 35 |
| pH value | 7.5 | 8.0 | 7.7 | 7.9 |
| Ca, p.p.m. | 40.0 | 40.0 | 32.0 | 26.7 |
| Mg, p.p.m. | 15.0 | 12.6 | 13.6 | 9.1 |
| $SO_4$, p.p.m. | 44.0 | 39.7 | 26.1 | 12.2 |
| $HCO_3$, p.p.m. | 143.5 | 139.8 | 153.4 | 116.0 |

The average for sodium was not calculated because of the number of negative values, and the generally low and doubtful values.

A comparison of the irrigation waters can be made from the above table. It will be noted that the T.D.S. and N.v.D.S. in Brooks irrigation water are greater than in Lake Newell irrigation water, while the reverse is true for magnesium, sulphate and bicarbonate. The total solids, calcium and sulphate are lower in the Picture Butte than in the Brooks or Lake Newell waters, but the bicarbonate is greater. The averages for Lethbridge are lower in all cases. It would appear from this comparison that water of the Lethbridge Northern Irrigation district contains a lower salt content than that of the

Eastern Irrigation District. This is probably due to the fact that the water is being used closer to its source and has not had the same chance to pick up salts.

A comparison of these analyses with those given by Greaves and Hirst (8,9) or with analyses of streams used for irrigation as given by Clark (3) shows that these waters are relatively low in dissolved salts. The salts present in these concentrations are not harmful to the soil or growing plants. These waters would be classed as hard waters because of their calcium and magnesium carbonate content. This is fortunate since "hard waters tend to make land soft while soft waters tend to make land hard." Table 8 also shows the variability of waters.

Table 9 shows the analyses of soil samples collected at the Lethbridge Experimental Farm. The results are averages of four determinations. The calcium content as determined by the two methods agrees very well. It is to be expected that the calcium as determined indirectly by the "Parr" carbon apparatus would be higher than the calcium determined by the total calcium method because there is a certain error involved. Part of the carbon dioxide released comes from carbonates other than calcium carbonate and when calculated as calcium carbonate it will give a figure that is too high. The calcium content of the irrigated and non-irrigated profiles are very similar. There appears to have been very little leaching of calcium, although leaching of calcium has been reported by other workers (2, 31). The main

TABLE 9

SUMMARY OF ANALYSES OF SOIL PROFILES COLLECTED AT LETHBRIDGE, SEPTEMBER, 1939

| | | $CO_2$ by "Parr" carbon apparatus | | | | Water soluble salts | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample | Depth (ins.) | C % | $CaCO_3$ % | Ca % | Total Ca % | T.S. % | N.V.S. % | $CO_3$ % | $HCO_3$ % | Cl % | $SO_4$ % | Ca % | Mg % | Na % |
| | | | | | Irrigated samples | | | | | | | | | |
| 151 & 152 | 0-8 | 0.27 | 02.21 | 0.88 | 1.44 | 0.10 | 0.04 | 0.0 | 0.020 | 0.0 | 0.0 | 0.0 | 0.0 | |
| 153 & 154 | 8-14 | 2.53 | 21.07 | 8.45 | 8.33 | 0.10 | 0.04 | 0.0 | 0.017 | 0.0 | 0.0 | 0.0 | 0.0 | |
| 155 & 156 | 14-19 | 2.30 | 19.20 | 7.70 | 7.27 | 0.02 | 0.01 | 0.0 | 0.020 | 0.0 | 0.0 | 0.0 | 0.0 | |
| 157 & 158 | 19-28 | 1.87 | 15.70 | 6.27 | 5.40 | 0.04 | 0.02 | 0.0 | 0.020 | T. | 0.0 | 0.0 | 0.0 | |
| 159 & 160 | 28-38 | 1.72 | 14.40 | 5.77 | 5.47 | 0.07 | 0.02 | 0.0 | 0.018 | 0.0 | 0.0 | T. | T. | |
| 161 & 162 | 38-44 | 1.56 | 13.00 | 5.20 | 5.20 | 0.09 | 0.04 | 0.0 | 0.019 | 0.0 | T. | T. | T. | |
| 163 & 164 | 44-54 | 1.47 | 12.32 | 4.95 | 4.85 | 0.07 | 0.04 | 0.0 | 0.021 | 0.0 | T. | T. | T. | |
| | | | | | Non-irrigated samples | | | | | | | | | |
| 165 & 166 | 0-8 | 0.112 | 0.93 | 0.46 | 0.94 | 0.040 | 0.020 | 0.0 | 0.017 | 0.0 | 0.0 | T. | T. | |
| 167 & 168 | 8-14 | 2.24 | 18.70 | 7.47 | 7.27 | 0.043 | 0.020 | 0.0 | 0.017 | 0.0 | 0.0 | T. | T. | |
| 169 & 170 | 14-19 | 2.22 | 18.48 | 7.40 | 6.98 | 0.038 | 0.019 | 0.0 | 0.021 | 0.0 | 0.0 | T. | T. | |
| 171 & 172 | 19-28 | 2.08 | 17.50 | 7.00 | 6.30 | 0.040 | 0.017 | 0.0 | 0.027 | 0.0 | 0.0 | T. | T. | |
| 173 & 174 | 28-38 | 1.78 | 14.82 | 5.93 | 5.48 | 0.085 | 0.061 | 0.0 | 0.026 | 0.005 | T. | T. | T. | |
| 175 & 176 | 38-44 | 1.60 | 13.46 | 5.37 | 4.91 | 0.368 | 0.310 | 0.0 | 0.020 | 0.014 | 0.2 | 0.025 | 0.030 | 0.026 |
| 177 & 178 | 44-54 | 1.31 | 11.61 | 4.64 | 4.42 | 0.540 | 0.469 | 0.0 | 0.019 | 0.014 | 0.326 | 0.028 | 0.043 | 0.059 |

difference between the two profiles is in the soluble salt content. There are measurable quantities of chloride, sulphate, calcium and magnesium at a depth of 38" - 44" in the non-irrigated samples while there are only traces in the irrigated profile at this depth. Marshall and Palmer (22) have reported similar leaching although the soluble salt content of the original soil was much higher than is the case at Lethbridge.

## Miscellaneous Analyses

Table 10 gives a summary of the analyses of Elbow River water for the year 1934, after treatment at Glenmore Filter Plant, which is the main source of water for the City of Calgary. The analysis was supplied by James Younge, City Chemist, Calgary, Alberta. It will be noted that the salt content is highest during the winter months. The reason for this is that during the winter months the chief source of water in the river is from springs which are naturally carrying greater amounts of salts. The analyses of irrigation waters given in Tables 4 to 7 would appear to contradict this statement since they contain more salts in the spring of the year than in the fall. However, since no analyses of these waters for the winter months are available, no conclusion can be drawn. The first waters in an irrigation ditch in the spring of the year would pick up salts left by evaporation of the previous year's water. There would also be some movement of salts up to the surface along the

TABLE 10

SUMMARY OF ANALYSES OF ELBOW RIVER WATER AFTER TREATMENT AT GLENMORE FILTER PLANT, 1934

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bicarbonate alkalinity | 163.0 | 164.3 | 159.8 | 142.3 | 137.5 | 138.5 | 138.3 | 136.3 | 142.5 | 144.5 | 145.0 | 150.7 |
| pH value | 8.12 | 8.06 | 8.04 | 8.05 | 8.14 | 8.19 | 8.25 | 8.23 | 8.28 | 8.23 | 8.23 | 8.20 |
| Total hardness: | | | | | | | | | | | | |
| CaCO$_3$, p.p.m. | 208 | 211 | 205 | 191 | 184 | 175 | 170 | 175 | 177 | 185 | 192 | 200 |
| CaCO$_3$, gr. per imp.gal. | 14.6 | 14.8 | 14.3 | 13.4 | 12.9 | 12.3 | 11.9 | 12.3 | 12.4 | 12.9 | 13.4 | 14.0 |
| Mineral analyses--Ions expressed in parts per million | | | | | | | | | | | | |
| Ca | 56.5 | 58.9 | 55.0 | 50.8 | 51.1 | 48.4 | 44.8 | 45.8 | 44.3 | 50.5 | 51.3 | 54.5 |
| Mg | 16.4 | 15.8 | 16.6 | 15.8 | 13.8 | 13.3 | 14.4 | 14.9 | 16.5 | 14.5 | 15.6 | 15.7 |
| Na (diff.) | 1.4 | 2.1 | 4.4 | 2.5 | 3.4 | 2.1 | 3.4 | 1.4 | 3.7 | 0.9 | 1.6 | 2.5 |
| SO$_4$ | 46.5 | 48.8 | 51.2 | 52.5 | 50.6 | 38.8 | 37.4 | 37.1 | 39.8 | 39.0 | 47.8 | 52.2 |
| HCO$_3$ | 199.0 | 200.5 | 195.0 | 174.0 | 167.8 | 169.0 | 168.7 | 166.3 | 174.0 | 176.3 | 177.0 | 183.8 |
| Cl | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 | 1.0 | 1.0 | 0.0 | 0.0 |
| F | 0.4 | 0.3 | 0.3 | 0.2 | 0.3 | 0.4 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.3 |
| Fe | *<0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Reacting values = equivalents per million | | | | | | | | | | | | |
| Na | 0.06 | 0.09 | 0.19 | 0.11 | 0.15 | 0.09 | 0.15 | 0.06 | 0.16 | 0.04 | 0.07 | 0.11 |
| Ca | 2.82 | 2.94 | 2.74 | 2.54 | 2.55 | 2.42 | 2.24 | 2.29 | 2.21 | 2.52 | 2.56 | 2.72 |
| Mg | 1.35 | 1.30 | 1.36 | 1.30 | 1.13 | 1.09 | 1.18 | 1.23 | 1.36 | 1.19 | 1.28 | 1.29 |
| SO$_4$ | 0.95 | 1.02 | 1.07 | 1.09 | 1.06 | 0.81 | 0.78 | 0.77 | 0.83 | 0.81 | 1.00 | 1.09 |
| HCO$_3$ | 3.26 | 3.29 | 3.20 | 2.85 | 2.75 | 2.77 | 2.76 | 2.72 | 2.85 | 2.89 | 2.90 | 3.01 |
| Cl | | | | | | | | 0.06 | 0.03 | 0.03 | | |
| F | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 | 0.02 | 0.02 | 0.03 | 0.02 | 0.02 | 0.01 | 0.02 |

dry ditches in the fall and early spring of the year. This lower salt content in summer is favorable to the use of water for irrigation since it is required primarily in the months of lowest salt content. Small amounts of chloride are reported only for August, September and October. Liquid chlorine is used to sterilize city water supplies. The amount used at Calgary varies from one-half to five pounds of chlorine per million gallons of water. The average for the year 1935 was one and one-half pounds of chlorine per million gallons of water. This free chlorine usually disappears before reaching the consumers' taps. Small amounts of chloride will be found from this source. However, the dilution of the sewage on returning to the river is manifold. The amount of chloride getting into irrigation waters from this source would be negligible.

Table 11 shows an analysis of Bow River water at Calgary. There is little if any difference between the salt content of the Elbow and the Bow. The Elbow joins the Bow at Calgary.

Table 12 gives analyses of water from the Bow River taken from above the Bassano dam, at Bassano, Alberta. While these analyses are not complete and were not taken in the same year, they tend to show the effect of spring runoff in the mountains on the composition of river waters. The low salt content of the samples taken in May, 1927, is probably due to the greater volume of water flowing at this time of year while the higher salt content of the other samples might be

## TABLE 11

## CHEMICAL ANALYSIS OF THE BOW RIVER WATER

| | Parts per million |
|---|---|
| Residue on evaporation | 212 |
| Loss on ignition | 77 |
| Fixed residue | 135 |
| Silica $SiO_2$ | 14.4 |
| Alumina $Al_2O_3$ | 1.5 |
| Iron Oxide $Fe_2O_3$ | 0.1 |
| Lime $CaO$ | 71.4 |
| Magnesia $MgO$ | 25.5 |
| Calcium $Ca$ | 51.03 |
| Magnesium $Mg$ | 15.4 |
| Sodium $Na$ (diff.) | 2.53 |
| Sulphate $SO_4$ | 47.1 |
| Chloride $Cl$ | nil |
| Nitrate $NO_3$ | trace |
| Carbonate $CO_3$ | nil |
| Bicarbonate $HCO_3$ | 179 |
| Bicarbonate alkalinity $CaCO_3$ | 147 |
| Carbonate alkalinity $CaCO_3$ | nil |
| Hydroxide alkalinity $CaCO_3$ | nil |
| Total hardness (soap method) $CaCO_3$ | 185 |
| Total hardness (soda reagent) $CaCO_3$ | 181 |
| Total hardness (analysis) $CaCO_3$ | 194 |
| Noncarbonate hardness $CaCO_3$ | 33 |
| Temporary hardness $CaCO_3$ | 70 |

Sample taken from Bow River intake, Calgary water supply, February 2nd, 1927, 2:00 p.m.

## TABLE 12

## ANALYSES OF WATER TAKEN FROM ABOVE THE DAM AT BASSANO, ALBERTA

(Parts per million)

| Date collected: | May 27, 1927 | May 27, 1927 | Aug. 15, 1927 | Sept. 7, 1928 | Oct. 5, 1928 | Nov. 1, 1928 |
|---|---|---|---|---|---|---|
| CaO | 58.5 | 58.5 | 62.95 | 70.00 | 67.2 | 72.8 |
| MgO | 23.0 | 24.6 | 21.45 | 22.40 | 29.2 | 30.2 |
| $Na_2O$ | 8.0 | 18.9 | -- | -- | -- | -- |
| $SO_3$ | 34.6 | 33.7 | 24.43 | 24.95 | 28.7 | 32.4 |
| $CO_2$ | 41.9 | 42.3 | 118.80 | 101.20 | 132.0 | 125.4 |
| Cl | -- | -- | 0.0 | T. | T. | T. |
| $NO_3$ | -- | -- | -- | 0.0 | 0.0 | 0.0 |
| TOTAL | 166.0 | 178.0 | 227.6 | 218.55 | 257.1 | 260.8 |

[illegible]

[illegible]

([illegible])

| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
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due to the fact that springs make up a greater percentage of the total supply in the fall of the year. This, however, is very variable since heavy rains would to some extent change the picture. Rains on the other hand might wash in salts from the surrounding country.

Table 13 shows analyses of water from various sources throughout Alberta. The table is arranged to show the increase in salt content at successive distances downstream from the source. Lake Louise which would receive most of its water from melting snow and rain is very low in salt content. The lake drains into the Bow River and there is a gradual increase in salt content as the water proceeds downstream. The salt content at Bassano is very much higher than at Lake Louise.

Crowsnest River at Coleman, also has a low salt content. There is a noticeable increase in salt content of the river at Blairmore; this is particularly true of the sulphate. The increase is probably due to drainage from the coal mines. The Crowsnest River flows into the Old Man River. The salt content at Macleod is lower than at Blairmore; this is probably due to dilution by less concentrated waters.

The Highwood River at the town of High River has a relatively high salt content as compared to other samples taken in or near the mountains. This is probably due to drainage from the Turner Valley oil fields. However, a higher sodium chloride content would be expected if this drainage from the oil wells were appreciable.

## TABLE 13

## WATER ANALYSES

(parts per million)

| | Total solids | $MgCO_3$ | $CaCO_3$ | $CaSO_4$ | NaCl | O.M. | Total hardness | $CO_3$ hardness | Non-$CO_3$ hardness | Alkalinity |
|---|---|---|---|---|---|---|---|---|---|---|
| Lake Louise - (Lake) | 135 | 24 | 76 | 12 | 2 | 16 | 113 | 104 | 9 | 104 |
| Bassano - Bow River | 262 | 117 | 52 | 66 | 10 | 6 | 240 | 191 | 49 | 101 |
| Coleman - Crowsnest River | 180 | 46 | 90 | 19 | 3 | 15 | 159 | 145 | 14 | 145 |
| Blairmore - Crowsnest River | 250 | 73 | 84 | 60 | 6 | 21 | 214 | 170 | 44 | 170 |
| Macleod - Old Man River | 196 | 48 | 98 | 24 | 3 | 15 | 172 | 155 | 17 | 155 |
| High River - Highwood River | 311 | 69 | 153 | 56 | 4 | 19 | 275 | 235 | 40 | 235 |
| Cardston - Lee Creek | 324 | 98 | 156 | 22 | 2 | 24 | 288 | 272 | 16 | 272 |
| Med. Hat - South Sask. River | 326 | 100 | 123 | 61 | 6 | 20 | 287 | 242 | 45 | 242 |
| Drumheller - Red Deer River | 330 | 81 | 154 | 69 | 8 | 10 | 301 | 250 | 51 | 250 |
| Edmonton - Sask. River | 292 | 84 | 75 | 86 | 5 | 33 | 238 | 175 | 63 | |
| Athabaska - Athabaska River | 250 | 69 | 85 | 44 | 5 | 50 | 199 | 167 | 32 | 167 |

Analyses by J. A. Kelso, Provincial Analyst.

The South Saskatchewan River at Medicine Hat represents a mixing of all the above mentioned streams. The total solid content is higher than at points farther upstream. The Red Deer River at Drumheller is also comparatively high in salt content. The North Saskatchewan River at Edmonton and the Athabaska River at Athabaska are included only as a point of interest. They represent waters from the more humid part of the province, and although the samples were taken farther from the source than those in the south of the province, their salt content is lower.

While the addition of solid contents to river waters of southern Alberta by coal mines, oil wells, and other sources may or may not be important, the table does tend to show a salt increase in the downward course of the streams. It must be kept in mind, however, that the salt content of any surface water will vary considerably and it would be fallacious to draw any definite conclusions from the analyses given in Table 13.

## The Geologic Origin of Salts in Alberta Waters

To a certain extent the salinity of a water is determined by its geologic environment, that is, it depends upon the solubility of the rocks from which the solid contents are derived. Clarke (3) makes the following statement:

"In a stream issuing from an area of crystalline rocks the salinity is generally low, usually less than 100

parts per million, and the same is true of waters flowing from areas of shale or sandstone. A limestone water on the other hand, is much higher in salinity, carrying as much as 200 parts per million and often more. In each class of rocks the solubility is in part dependent upon texture--whether a rock is compact or porous; firm and solid like marble, or of a loose structure like chalk..... Low salinity indicates that the solid contents of a water come from rocks of relatively low solubility, such as granite, for example, or shale and sandstone in a sedimentary area. High salinity, when compared with the composition of a water, may point either to a derivation from limestone, or else, in an arid region, to soluble salts in the soil. If much magnesium is present, it probably came from magnesium limestone or dolomite, and then a reference to the geologic character of the drainage area should show whether the supposition is correct."

An examination of any of the analyses reported here indicates that the main cations found in these waters are calcium and magnesium, and the main anions are bicarbonate and sulphate. The reason for calcium and magnesium being the dominant cations can be traced to the rock formations over which the waters flow. There are practically no igneous rocks in the Canadian Rockies. There are some very thin sections of volcanic dusts in the rock formations of the mountains and underlying the adjacent prairies, but these would probably have comparatively little effect on the composition of waters flowing over these areas. There is a small area of igneous rock near Field, British Columbia, some volcanics at Crowsnest extending north and south for some distance and a small wedge of volcanics (Purcell Lavas) in the Precambrian (which is marks and milling, and the edge is made [illegible] space of white or [illegible]. In [illegible] in such figures [illegible], [illegible] difficulties after [illegible]. It [illegible] part dependent upon texture--whether [illegible] line and solid line models, for a [illegible] that the [illegible] of relatively [illegible] [illegible] in the wall. If such [illegible] probably have [illegible] reference to [illegible] is [illegible].

In transcription of [illegible] the main [illegible] and the [illegible]. The [illegible] be [illegible] are [illegible] tion of the [illegible] would [illegible] of [illegible] of [illegible] thrust over the Cretaceous) at Waterton, Alberta. The Canadian Rockies are made up of sandstones, shales, limestones, dolomites and quartzites. Shales, slates and sandstones represent the end-products of aqueous decomposition, so that limestones and dolomite remain the chief source of dissolved materials in the water of the rivers and streams originating in the mountains. However, since the Rocky Mountains are made up of sedimentary rocks, they are likely to contain salts. The rock formations of the foothills and prairies are also of sedimentary origin and contain a certain amount of salts. It is thus seen that waters issuing from these areas will contain calcium, magnesium, carbonate and sulphate as their dominant ions. Analysis of the Bearpaw and Belly River formations east of the mountains have shown that these beds contain sodium sulphate and calcium sulphate (see Table 16). The effect of seepage from these beds shows up in salt crusts along deep cuts and banks.

## The Movement of Salts in Certain Irrigated Soils of Alberta

Table 14 shows the analyses of drainage water from eight representative drains of the Eastern Irrigation District. The total solids expressed in parts per million are averages of eight different drains. The salts are expressed in percent of the total. Without knowing the actual volumes flowing through the drains, one can draw no definite conclus-

## TABLE 14

## ANALYSES OF DRAINAGE WATERS FROM EIGHT REPRESENTATIVE DRAINS OF THE EASTERN IRRIGATION DISTRICT

(Compounds expressed in % of total solids)

| | 1924 | | 1925 | | 1926 | | 1927 | | 1928 | | 1929 | | 1930 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spring | Fall | Spring | Fall | Spring | Fall | Spring | Fall | Spring | Fall | Spring | Fall | Spring |
| $CaSO_4$ | 9.0 | 16 | 13 | 17 | 21 | 19 | 24 | 20 | 26 | 17 | 27 | 21 | 7 |
| $MgSO_4$ | 14.0 | 18 | 14 | 20 | 18 | 19 | 29 | 16 | 29 | 19 | 16 | 19 | 5 |
| $Na_2SO_4$ | 70.0 | 53 | 62 | 51 | 51 | 51 | 22 | 47 | 21 | 47 | 40 | 55 | 76 |
| $Mg\ CO_3$ | | 11 | | | | | | | | | | | |
| $Na_2CO_3$ | 7.0 | 2 | 5 | 9 | 7 | 8 | 20 | 15 | 21 | 15 | 13 | 2 | 9 |
| NaCl | | | 6 | 2 | 3 | 2 | 3 | 2 | 2 | 1 | 3 | 3 | 2 |
| $NaNO_3$ | | | | 1 | 0 | 1 | 2 | 0 | 1 | 1 | 1 | | 1 |
| | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Av. T.S., p.p.m. | 8630 | 7780 | 7259 | 4628 | 5100 | 4241 | 3345 | 4794 | 3625 | 4317 | 2831 | 3578 | 4005 |

ions as to the balance of salts in these soils, i.e., the ratio of the total amount of salts brought in by the irrigation water to the total amounts drained off by the drainage waters. However, considering the composition of the irrigation water used, viz., the Bow River and Lake Newell, which do not exceed 300 p.p.m. of total dissolved solids, as compared to these drainage waters, there would appear to be leaching of salts from the soil. It will be noted that there are large amounts of sodium sulphate in the drainage water while only small amounts, if any, of this salt are found in the irrigation waters. Marshal and Palmer (22) report a leaching of soluble salts from the soil and it is also shown in Table 9.

The salt content of spring and fall drainage waters is not consistent enough to say whether the spring drainage contains more salts than the fall or vice versa; there is considerable difference from one year to another. A great deal would depend on the amount of water being applied to the soil when the samples were collected. If a large excess of water were applied much of the water would run over the soil and into the drains. This would tend to dilute any water that percolated through the soil and into the drains. If, however, only a moderate amount of water were applied, the volume of drainage water would be small and its salt content relatively high.

Table 15 shows the composition of four samples of water taken in an area that is strongly affected by alkali,

near Brooks, Alberta. Such areas usually result from seepage or movement of salts to the surface from the subsoil under the influence of a high water table. Alkali crusts are quite common in low areas, particularly on sandy soils which permit a freer movement of water and salts. Proper and adequate drainage is essential in such areas.

Table 15. Analyses of water from alkali plots, May 29, 1924

| Site no.: | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Ca, p.p.m. | 503 | 604 | 300 | 419 |
| Mg, p.p.m. | 803 | 840 | 651 | 912 |
| Na (diff.) | 3310 | 4135 | 2413 | 10000 |
| $SO_4$, p.p.m. | 10756 | 13276 | 7876 | 25342 |
| $HCO_3$, p.p.m. | 686 | 277 | 575 | 256 |
| $CO_3$, p.p.m. | --- | --- | --- | --- |
| Total solids | 16225 | 18710 | 11340 | 36470 |

From the table it will be seen that these waters have solid contents of 1.62%, 1.87%, 1.13%, and 3.65% respectively. These very high amounts could never have come from the irrigation water. They must have been present in the soil before irrigation started or have accumulated in these areas since.

In some parts of irrigated areas, lakes and sloughs have become strongly alkaline as a result of drainage from irrigated lands. This is shown by the salt crusts that appear around such bodies of water, or more particularly in low areas where water movement brings the salts to the surface.

Table 16 gives analyses of alkali crusts caused by irrigation, and analyses of shale (35,36).

Table 16.

Analyses of surface crust and shale

| Location | Depth | Non-volatile salts | $HCO_3$ & $CO_3$ | Cl | $SO_4$ | Ca | Mg | Na |
|---|---|---|---|---|---|---|---|---|
| | | % | % | % | % | % | % | % |
| 14-20-13 Nr.Patricia | Surf. | 22.027 | 0.049 | 0.065 | 15.080 | 0.205 | 0.352 | 6.325 |
| 36-19-15 7 miles N.W. of Brooks | " | 21.065 | 0.092 | 0.092 | 15.153 | 1.077 | 0.689 | 4.054 |
| | | Analyses of shale | | | | | | |
| Alkali incrustation seeping from shale | " | | .06 | --- | 31.94 | 0.26 | 0.36 | 14.35 |
| Yellowish brown shale | 20' below surf. | | -- | --- | .61 | 0.08 | 0.01 | 0.18 |

The principal salt shown in the above analyses is sodium sulphate. Other analyses of the underlying formations of southern Alberta by the Department of Soils have shown sodium sulphate to be one of the main salts present. The Bearpaw shale, which underlies much of the irrigated areas, commonly contains large selenite (gypsum) crystals between the laminations of the shale. Smaller crystals of salt are often found in soil

borings at depths of 3 to 5 feet in old lake beds. Gypsum is not as soluble as sodium sulphate and would not be brought to the surface as readily as the latter salt.

Raising of the water table is often responsible for bringing salts to the surface. In speaking of the effect of the water table, Harris (12) says:

"Headden made a rather detailed study of the effect of seasonal movement of water tables from which he concluded that as the water fell much of the salts in the free water was retained by the soil so that the free water gradually became weaker as it sank and again increased as it rose. He found that the kind and quantity of salts in the soil solution differed markedly from those found in the free ground water or from the alkali incrustations on top of alkali soil. Certain of the soluble salts were absorbed by the soil, while others moved somewhat more freely. Calcium sulphate was the most abundant salt in the soil solution with magnesium sulphate second, while sodium sulphate formed considerable of the efforescent matter on the surface, and the salts next to the surface. Sodium chloride did not separate as readily as some of the other salts. Very little calcium sulphate left the soil to form part of the incrustation."

Clark (3) points out that Utah Lake, Utah, in the 20 years intervening between the earliest and latest analyses, has undergone a thorough transformation and its salinity doubled. From a fresh water of the sulphate type it has become distinctly saline, and this change is probably the result of irrigation. Its natural supplies have been diverted

into irrigation ditches and at the same time salts have been leached out from the soil and washed into the lake.

## The Limits of Salt Concentration of Irrigation Water

The amount of salts that plants can endure varies widely. Kelley has done extensive work on the permissible composition and concentration of irrigation water (15). He sums up the problem as follows:

"The limit of permissible salt concentration of irrigation water is greatly influenced by variables inherent in the soil, the climatic conditions, and the kind of crops grown. It is of the greatest importance to apply saline irrigation water in quantities in excess of the crop requirements, in order that some leaching of the root zone will take place. Therefore the maintenance of good drainage condition in the soil is very important. Salts, whether native to the soil or applied in the irrigation water, cannot be removed effectively unless water can percolate through the soil, and this can never be accomplished adequately where the ground water is near the surface."

The following observations regarding the upper limit of alkali in water as summarized by Harris (12) should be interpreted as applicable to the conditions under which the observations were made, rather than as general guides that apply with precision to all conditions.

"Hilgard states that although 685 parts per million of the common alkali salts should be the limit under most conditions, the nature of the salts will modify the limits considerably. As little as 342 parts per million of sodium carbonate has in some instances caused serious injury in three or four years, while as much as 2739 parts per million of the less toxic salts would not be harmful. From his work in California, Makie states that where the salts are principally bicarbonate and chloride of sodium, irrigation water containing more than 600 to 700 parts per million of salt should not be applied except to porous, well-drained soils. Guthrie considers 500 parts per million of sodium carbonate as a tolerable quantity of this salt even when as much as 150 parts per million of sodium chloride are also present.

"Where the salts are more of the sodium-sulphate type, larger quantities are permissible. Forbes states that with good drainage 1000 parts per million of salts in irrigation water is an objectionable but permissible degree of salinity for soils of the Salt River, Arizona." He goes on to give a number of instances where waters containing even as high as 8000 p.p.m. of total solids have been used with special crops. He also cites a number of cases where land had to be abandoned after irrigating with water containing such large quantities of salts.

## The Probable Effects of Alberta Irrigation Waters on the Soil

From a study of the composition of Alberta irrigation waters, it would appear that any great chemical effects that these waters would have on the soil would not be from the salts in the waters themselves but from a readjustment of the salts already present in the soil. It has been stated by Kelley, Brown and Liebig Jr. (16) that the ratio of sodium plus potassium to calcium plus magnesium in irrigation waters should not exceed 1:1. Alberta irrigation waters analyzed have a very favorable ratio. They are not only very low in sodium content but are also relatively low in total salt content.

These waters would no doubt contain small amounts of nitrate and phosphate which would be beneficial to the growing crops. The small amounts of sodium and potassium present would do no harm to growing crops since the quantities of these elements already in the soil would in most cases far exceed the amounts brought in by the irrigation water. As has been shown, there are larger quantities of these elements leached from the soil than added to it by the irrigation water (see Table 14).

The calcium and magnesium in the waters would be largely beneficial. A dispersing effect of calcium on the water stable granules of the soil when the calcium was added to the soil in large amounts was reported by Peele (24). The amount of calcium and magnesium present in Alberta irrigation

waters is, however, so low that this effect could not occur. It would appear that leaching of these elements would occur rather than an accumulation. If an increase in calcium did occur through the use of irrigation waters, it would have a beneficial effect rather than a harmful effect on the physical properties of most soils, since calcium salts generally cause flocculation.

The amount of calcium, magnesium, and sulphur carried to the soil in these irrigation waters is much in excess of the requirements of crop plants. Any leaching of these elements to a lower level is partially overcome by their addition in the water. This is shown in Table 17, which gives the average amounts of calcium, magnesium and sulphur in one acre foot of irrigation water from the four locations where samples were taken. The table also shows the amounts of these elements in the grain and straw of a 30-bushel per acre crop of wheat and in the roots and leaves of a 15-ton per acre sugar beet crop.

Table 17. Pounds of Ca, Mg and S in one acre foot of irrigation waters, a 30-bushel crop of wheat, and a 15-ton crop of sugar beets

| | In one acre foot of water | | | | *In crop | |
|---|---|---|---|---|---|---|
| | Lake Newell | Brooks | Picture Butte | Lethbridge | Wheat, 30 bu. grain & straw | **Mangels 15 tons |
| | lb. | lb. | lb. | lb. | lb. | lb. |
| Ca | 109 | 109 | 87 | 78 | 6.7 | 20.9 |
| Mg | 42 | 34 | 37 | 34 | 4.2 | 17.1 |
| S | 40 | 39 | 24 | 11 | 7.9 | 10.2 |

* Recalculated from Warrington's table of crop composition, p. 550, "Soil Conditions and Plant Growth" - E.J. Russell. 7th ed., 1937. Longmans, Green and Co. Ltd., London.

**No satisfactory analyses for sugar beets could be found.

Any important physical changes brought about in the soil from the use of these waters would be produced by: (1) movement of salts already present in the soil, (2) suspended material carried to the soil, (3) changes produced by the simple addition of water to the soil. The first effect was discussed when dealing with chemical changes. The second effect was referred to in the review of literature. It is hard to say just to what extent suspended material would affect the physical properties of soils when these irrigation waters are used. A more extensive investigation would have to be carried out in the field to get conclusive results.

The physical effects of water on the soil, disregarding dissolved solids or suspended material, is best explained by the following quotation from Baver's book, "Soil Physics"(1):

"Effects of Irrigation - Sokolovsky has emphasized the fact that the problem of the formation of good structure requires special consideration under irrigation. The breakdown of aggregation in the surface during irrigation leads to crust formation, which produces unfavorable air and water relations for plant growth. The water that is added is thereby rendered partially ineffective for crop production. The economic importance of this crusting effect is well illustrated in the worlds of Sokolovsky, who says: 'Here also extremely unfavorable physical properties of the soil draw our attention, properties which make tilling hard and difficult, entail considerable waste of water due to surface drying (the crust): All this heavily affects the plant, for it always experiences

a deficit in water; the seeds, when germinating, suffer from lack of air and the seedlings force their way through the crust with difficulty; the crust, when cracking, cuts the delicate stalks as with a knife; water, so precious in these regions, is to be greatly wasted without economy.'

"Cole has observed that irrigation of several California soils by the basin method, where the whole surface is covered with water, causes a puddling of the surface. This puddling action increases the cloddiness of the soil and obviates the beneficial effects of any tillage operations prior to irrigation. In general, the finer the condition of the soil surface before irrigation, the coarser are the clods after the water is applied.

"It appears, therefore, that the effect of irrigation water in the arid regions on the structure of the surface soil is similar to that of natural rain in the humid regions, unless water-stable aggregates exist in the surface layer; water causes dispersion of the secondary particles and a decrease in non-capillary porosity follows. Alfalfa and grass sods have the same desirable effects under irrigation as they have in humid regions."

By applying water to dry Lethbridge soil and rubbing it in the palm of the hand one may obtain some idea of its water-stable granules. Granules that are formed on drying break down almost immediately when water is added to this soil.

## SUMMARY

Irrigation water samples were collected throughout the irrigation season, 1941, at four locations in southern Alberta, viz., Lake Newell, Brooks, Picture Butte and Lethbridge. These samples were analyzed for total solids, non-volatile solids, calcium, magnesium, sulphate, carbonate and bicarbonate. Suspended material was determined on the samples collected at Lethbridge.

These waters are relatively low in salt content as compared to waters used for irrigation in parts of the United States. In general there was a slight reduction in salt content towards the end of the season. Except for one increase the Lethbridge samples had about the same salt content throughout the irrigation season.

The average salt content for irrigation water from Lethbridge is lower than for any of the other sets of samples. The Picture Butte samples contain on the average more salts than the Lethbridge samples but less than the Brooks or Lake Newell samples. The latter contain about equal amounts. A comparison of the salts found in the waters with the composition of the rocks over which they flow shows that dolomite and limestone are the chief sources of these salts.

The use of these waters for irrigation will have four effects on the soil, viz., (1) salts will be leached from the soil or moved and concentrated in certain areas; (2) varying amounts of plant foods will be added to the soil in the

irrigation water; (3) varying amounts of suspended material (silt), which will affect the physical properties of the soil, will be deposited on the land; (4) the mere addition of water to the soil will bring about changes in the physical properties of the soil.

Two profiles, one of irrigated soil and the other of non-irrigated soil, from Lethbridge Experimental Farm, were analyzed for inorganic carbon, total calcium and water soluble salts. The results show that some leaching of soluble salts had taken place in the irrigated land. No apparent leaching of calcium had taken place in the irrigated soil, although other workers had reported leaching of calcium.

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